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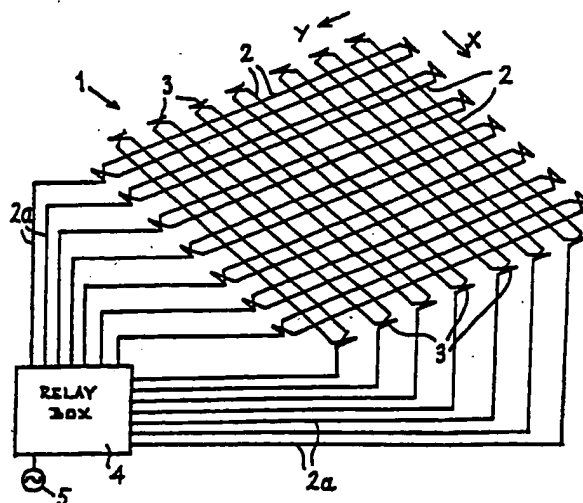
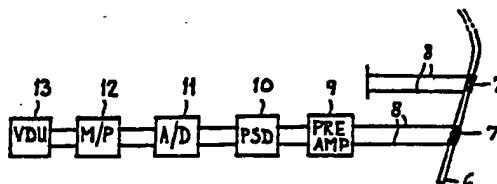
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>5</sup> :</b>  <b>A61B 5/06, G01V 3/10</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 92/03090</b>  <b>(43) International Publication Date:</b> 5 March 1992 (05.03.92)		
<table border="0" style="width: 100%;"> <tr> <td style="width: 50%; vertical-align: top;"> <p><b>(21) International Application Number:</b> PCT/GB91/01431</p> <p><b>(22) International Filing Date:</b> 23 August 1991 (23.08.91)</p> <p><b>(30) Priority data:</b> 9018660.2      24 August 1990 (24.08.90)      GB</p> <p><b>(71) Applicant (for all designated States except US):</b> IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY &amp; MEDICINE[GB/GB]; London SW7 2AZ (GB).</p> <p><b>(72) Inventors; and</b>  <b>(75) Inventors/Applicants (for US only):</b> GUY, Christopher, Neil [GB/GB]; 62 Beechdale Road, London SW7 (GB). GILLES, Duncan, Fyfe [GB/GB]; 75 Kingsmead Road, Tushill, London SW2 3HZ (GB).</p> </td> <td style="width: 50%; vertical-align: top;"> <p><b>(74) Agents:</b> WARREN, Keith, Stanley et al.; Baron &amp; Warren, 18 South End, Kensington, London W8 5BU (GB).</p> <p><b>(81) Designates States:</b> AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CI (OAPI patent), CM (OAPI patent), CS, DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), GN (OAPI patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MN, MR (OAPI patent), MW, NL, NL (European patent), NO, PL, RO, SD, SE, SE (European patent), SN (OAPI patent), SU*, TD (OAPI patent), TG (OAPI patent), US.</p> <p><b>Published</b>  <i>With international search report.</i>  <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p> </td> </tr> </table>			<p><b>(21) International Application Number:</b> PCT/GB91/01431</p> <p><b>(22) International Filing Date:</b> 23 August 1991 (23.08.91)</p> <p><b>(30) Priority data:</b> 9018660.2      24 August 1990 (24.08.90)      GB</p> <p><b>(71) Applicant (for all designated States except US):</b> IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY &amp; MEDICINE[GB/GB]; London SW7 2AZ (GB).</p> <p><b>(72) Inventors; and</b>  <b>(75) Inventors/Applicants (for US only):</b> GUY, Christopher, Neil [GB/GB]; 62 Beechdale Road, London SW7 (GB). GILLES, Duncan, Fyfe [GB/GB]; 75 Kingsmead Road, Tushill, London SW2 3HZ (GB).</p>	<p><b>(74) Agents:</b> WARREN, Keith, Stanley et al.; Baron &amp; Warren, 18 South End, Kensington, London W8 5BU (GB).</p> <p><b>(81) Designates States:</b> AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CI (OAPI patent), CM (OAPI patent), CS, DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), GN (OAPI patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MN, MR (OAPI patent), MW, NL, NL (European patent), NO, PL, RO, SD, SE, SE (European patent), SN (OAPI patent), SU*, TD (OAPI patent), TG (OAPI patent), US.</p> <p><b>Published</b>  <i>With international search report.</i>  <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>
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**(54) Title:** PROBE SYSTEM**(57) Abstract**

A probe system for use in carrying out inspections in an enclosed, non-conducting environment, such as an endoscope for use in carrying out internal inspections of a human or animal patient, comprises sensing coils (7) mounted at spaced positions along the probe (6) for movement with the latter and a planar grid array (1) of antennas (2) which is disposed adjacent the environment. AC electrical signals are supplied to the antennas, either simultaneously or sequentially, by an electrical source (4,5) so as to induce corresponding voltage signals in the sensing coils (7). When the probe (6) is introduced into the environment, the induced signals, converted to a digital format, are processed by a microprocessor (12) to produce a visual indication of the three dimensional location of the probe (6) with respect to the antenna array (1).



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Any designation of "SU" has effect in the Russian Federation. It is not yet known whether any such designation has effect in other States of the former Soviet Union.

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WO 92/03090

PCT/GB91/01431

-1-

PROBE SYSTEM

This invention relates to probe systems for use in an enclosed, non-conducting environment, such as a human or animal body. Such probe systems are particularly suitable for use in endoscopy and, more particularly, colonoscopy.

It is of particular importance to determine the precise location of a probe, such as an endoscope, within the body of a patient. The absence of an accurate probe locating system can cause patient complications ranging from unnecessary pain to actual perforation, instrument damage, and serious mistaken diagnosis. A further complication is that elongate probes have a tendency to form looping configurations. One probe locating technique is to employ x-ray imaging, but x-ray systems suffer from several disadvantages. They are relatively expensive and, hence, are not readily available in most endoscopic units. In addition, x-ray systems now face increasing restrictions on their use, such as protective clothing, etc. Furthermore, they produce only a relatively small two dimensional image, which is somewhat lacking in detail.

It is an object of the present invention to provide a probe system which is capable of being accurately located within an enclosed non-conducting environment, such as a human or animal body, and which does not rely on x-ray imaging for its locational information.

Accordingly, the invention consists in a probe system for use in an enclosed, non-conducting environment and including a probe, characterised by at least one sensing coil movable with the probe, an array of antennas, an electrical source for supplying each antenna, either simultaneously or sequentially, with an AC electrical signal for inducing a corresponding electrical signal in the or each sensing coil, and electronic processing means connected to

WO 92/03090

PCT/GB91/01431

-2-

the sensing coil(s) for processing the induced signals and producing an indication of the three dimensional location of the probe with respect to the antenna array.

The invention makes use of the variation in mutual inductance between a sensing coil and the antenna array. By detecting the signals induced in the or each sensing coil by each transmitting antenna of the array, and solving field equations associated with each antenna location, the three dimensional location of the sensing coil and, hence, the probe, can be established.

In one embodiment of the invention, the sensing coil is mounted to move with the probe, which has coordinates  $X, Y, Z$  and polar angles  $\theta, \phi$ , and the antenna array which is in the form of a planar grid of mutually orthogonal antennas is mounted adjacent the enclosed non-conductive environment to be accessed by the probe with the columns and rows of the grid running respectively parallel to the  $X$  and  $Y$  axes. When a single antenna of the grid carries an AC current signal, a voltage is induced in the sensing coil which varies in a completely defined manner with respect to the relative coordinates and the sensing coil angles. When each antenna of the grid is energised in turn with a short current pulse supplied from the electrical source, the sequence of signals produced by the sensing coil may be analysed to yield the sensing coil coordinates and angles. When used in endoscopic applications, the antenna array is mounted on the patient bed underneath a patient with the columns and rows of the grid running respectively parallel to the  $X$  and  $Y$  axes.

A probe, such as an endoscope, typically comprises an elongate element, in which event information concerning the location of various sections of the probe may be required. Moreover, in addition to the positional information, it may be desirable to detect the occurrence of accidental loops formed in the probe behind its tip. In

WO 92/03090

PCT/GB91/01431

-3-

one embodiment, at least one sensing coil is movable longitudinally with respect to the probe along at least a portion of its length. By moving the sensing coil along the probe and detecting its successive positions, the existence of looped configurations or other problems may be detected. Alternatively, two or more sensing coils may be mounted in spaced relationship along the length of the probe, one preferably being located adjacent the tip of the probe and the others remote from the tip. By employing such a plurality of sensing coils, data concerning the location of each portion of the probe can be obtained. Moreover, even with only two sensing coils, the relative phase of the induced signal in the two sensors, when a single antenna in the array is energised, provides information about a twist along the length of the probe and thus can be monitored to give warning of an impending loop formation. The exact location of a loop may be detected by mounting several sensors along the length of the probe. Changes in relative phase will then pinpoint which sections are twisted and, hence, looped.

With the invention, having obtained three dimensional coordinates of at least one point on the probe and at least two known points on the surface of the enclosed non-conducting environment, the electronic processing means may operate to compute an estimate of the position of the probe inside the environment. This task falls into two parts, namely, interpolating the known points to find the centre line of the probe and, secondly, estimating the tip position in the environment. The first task is relatively trivial if sufficient points are known whilst the second task is more difficult. For example, in the case of colonoscopy, although there is a great deal of variation in individual colons, there are certain anatomical properties that can be used. Hence, the sigmoid and transverse colons are known to mobile, whereas the ascending and descending

WO 92/03090

PCT/GB91/01431

-4-

colons are relatively fixed. Thus, by looking at the dynamic behaviour of different points on the endoscope, the position in the colon can be estimated. For example, if a point moves in a direction orthogonal to the endoscope body it is probable that that point is either in the sigmoid or transverse colon. Evidence can also be gained from the configuration of various parts of the endoscope. Further information is available from the inserted length of endoscope. This information must be incrementally upgraded since manoeuvres, such as pulling back to straighten the sigmoid colon, alter the relationship between the inserted length and the position of the endoscope tip. The algorithm for computing the probe position may be one in which the uncertainty is as far as possible resolved by combining several sources of information. Once the position of the tip is estimated, it is a comparatively simple matter to draw the endoscope and indicate the surrounding haustral folds.

The electrical source is preferably adapted to supply the antennas with AC sine wave signals having frequencies in the low to medium audio ranges, that is 1 to 10 kHz and, preferably, of the order of 2 kHz. Alternatively, the generator may be adapted to supply the antennas with radio frequency AC electrical signals.

In one convenient embodiment of the invention, for use with an endoscope, a plurality of sensing coils, for example seven, and their connecting leads are mounted at intervals inside a flexible protective plastics sheath, for example, a plastic tube approximately 2m in length and having an external diameter less than 2.5mm, which allows insertion of the coils into the biopsy channel of the endoscope. Location and imaging of the entire length of the scope inside a patient can thus be obtained on an unmodified endoscope by inserting the sheath into the biopsy channel and operating the sensing coil energisation

WO 92/03090

PCT/GB91/01431

-5-

sequence. In another embodiment requiring modification of a conventional endoscope, sensing coils are permanently mounted at intervals along the length of the scope. These coils are mounted substantially coaxially with the endoscope axis and are disposed between the metallic braid and the outer plastics sheath of the endoscope. With this embodiment, continuous monitoring of the endoscope location is obtained without any obstruction to the biopsy channel.

The or each sensing coil may be connectable to the electronic processing means via a preamplifier, a phase sensitive detector, which produces a demodulated DC analogue voltage correspondingly to the AC voltage signal induced in the sensing coil by the antenna array, and an analogue-to-digital (A/D) converter which digitises the coil signal for processing by the electronic processing means to produce a final graphical image. Where the probe system includes a plurality of sensing coils, each sensing coil may have its own preamplifier, phase sensitive detector and A/D converter chain or, alternatively, a multiplexing arrangement may be utilised for sequentially detecting the signal voltages induced in the sensing coils and utilising a single preamplifier, phase sensitive detector and A/D converter chain.

Preferably, the antenna array is in the form of a substantially planar grid or matrix. Some or all of the antenna of the array may comprise dipole antennas. The use of dipole antennas reduces the signal contribution from the wire leads and the return wire.

The planar grid array of antennas may, for example, comprise two orthogonal sets of seven or more long thin dipole coils. Each set provides enough data to compute the Z (height) and either X or Y components of the or each sensing coil position with respect to the array. This configuration in conjunction with the electronic processing

WO 92/03090

PCT/GB91/01431

-6-

means allows for a rapid computation of sensing coil position because the X and Y coordinates are separately determined.

Small errors in position may be produced by dipole coils having plain, short ends because these sections on, for example, the Y coils, produce small but defined contributions to the X component of the field and these contributions are not taken into account in the computation produced by the electronic processing means. In order effectively to reduce these contributions, the ends of the coil turns may be specially configured as so called "butterfly" end windings which alter an effective short single wire section into a dipole perpendicular to the longitudinal axis of each coil. The field from such an arrangement falls off with distance more rapidly than that of a single wire and thus the field contribution of the ends is very much reduced.

The electrical source for supplying AC electrical signals to the antenna array may be adapted simultaneously to energise each of the plurality of antennas of the array with a distinct or individual frequency. In this way, the time taken to establish the location of the probe may be reduced as all the antennas are transmitting simultaneously, each with its own distinctive frequency. Where the time taken to interrogate the or each sensing coil is not critical, the electrical source may operate at a single frequency energising each of the antennas in turn.

The present invention also consists in a method of locating a probe within the body of a human or animal subject, characterised by the steps of inserting the probe into the body of the subject, said probe having at least one sensing coil movable therewith, disposing an array of antennas adjacent the subject, energising each of the antennas, either simultaneously or sequentially, with an AC electrical signal, detecting the resulting signal induced



WO 92/03090

PCT/GB91/01431

-7-

in the or each sensing coil, and processing the detected signal(s) to produce an indication of the three dimensional location of the probe with respect to the antenna array.

Preferably, the method includes the further step of detecting the signals induced in one or more reference coils externally of the body of the subject, in order to establish the location of the body of the subject with respect to the antenna array.

In order that the present invention may be more readily understood, reference will now be made to the accompanying drawings, in which:-

Figure 1 schematically illustrates one embodiment of the invention,

Figure 2 schematically illustrates the winding configuration of each dipole antenna of the antenna grid,

Figure 3 is a diagram utilised in applying a correction to the field equations in order to take into account the fact that the antenna wires are of finite length, and

Figure 4 is a graph illustrating the variation in the two components of the equation on which is based the algorithm for solving the field equations.

Referring to Figure 1 of the drawings, the probe system includes an array 1 of dipole antennas 2 in the form of a planar grid comprising two mutually orthogonal sets of seven elongated thin coils extending in X and Y directions. Each dipole antenna 2 may, for example, comprise a copper coil having twenty turns and typically have dimensions of 100cm x 5cm. The spacing between the antennas 2 within the grid array 1 is typically 7.5cm.

As illustrated in Figure 2, the ends 3 of each turn of a dipole antenna coil 2 are specially configured. The reason for this is that small errors in position would be produced by coils with plain short ends because these

WO 92/03090

PCT/GB91/01431

-8-

sections, for example, on the Y coils produce small but defined contributions to the X component of the field. By providing the turns with so-called "butterfly" end windings, as illustrated, these undesirable field contributions are effectively reduced. In effect, this arrangement alters a short single wire section at each end into a net dipole perpendicular to the longitudinal axis of the associated coil.

Each antenna 2 is connected via twisted leads 2a to a relay box 4 which is adapted sequentially to connect each antenna with an AC signal generator 5. In one example, the generator 5 is capable of generating a 9kHz sine wave signal having a peak current of 50 mA.

Associated with the antenna array 1 is an endoscopic probe 6 having seven sensing coils 7 mounted coaxially with the probe at spaced positions along its length, one of the sensing coils being mounted at or adjacent the tip of the probe. For the sake of convenience, only two coils 7 are illustrated. Each sensing coil 7 is wound about the probe between the metallic braid and the outer plastic sheath of the probe and typically comprises 800 turns of fine copper wire (48swg) on a tubular Mu metal core which is a commercially available soft ferro magnetic material with a high relative permeability (in the range 10,000-100,000). Each sensing coil 7 is connected via a screened twisted cable pair 8 to a preamplifier 9 which is in turn connected to a phase sensitive detector 10 for producing a DC voltage level proportional to the amplitude of the AC voltage induced in the associated sensing coil 7. The signals from the phase sensitive detector 10 are fed to an A/D converter 11 which produces digital signals dependent on the DC signal level at the output of the phase sensitive detector for processing by a microprocessor 12 and subsequent display on a video display unit 13 associated with the microprocessor. Only the chain of circuits 9,10 and 11

WO 92/03090

PCT/GB91/01431

-9-

associated with one sensing coil 7 is illustrated in Figure 1.

In using the system of Figure 1 for conducting an endoscopic inspection of a cavity or passage, for example, the colon, in the body of a human or animal patient, the planar antenna array 1 is disposed underneath the patient on the patient's bed. Conveniently, the antenna array is formed by winding the multi-turn coils of the antennas 2 in grooves cut accurately in a single large board that forms part of the patient's bed. Thus, the array is permanently in place and does not hinder the positioning and turning of the patient during an endoscopic procedure. Having positioned the patient on the antenna array, the endoscopic probe 6 is inserted into the colon of the patient, whereafter, each antenna 2 is energised in turn by the AC electrical source constituted by the relay box 4 and generators. The resulting signals induced in the sensing coils 7 are fed to the microprocessor 12 via the chain of circuits 9, 10 and 11 and the microprocessor interprets the signals in terms of the three dimensional locations of the probe. The X,Y and Z coordinates and the axial direction vector of each coil 7 can be established by comparing the signals induced from each antenna 2 and by solving certain field equations associated with each antenna location.

Additional sensing coils (not shown) may be placed in predetermined positions on the patient's body (body markers) so that the position of the torso can be estimated with respect to the array 1 which serves as a common reference frame. By this means, the position and configuration of the endoscope with respect to the patient's anatomy can be computed.

The determination of sensing coil positions by the microprocessor relies on the integral equation for the mutual inductance between two coils. For a general coil arrangement the equation (Von Neumann's formula) does not

WO 92/03090

PCT/GB91/01431

-10-

allow the direct determination of sensing coil coordinates from measurement of mutual inductance. For the purposes of the present invention, therefore, this is simplified in the following ways:

(i) Each sensing coil 7 has a small area and thus it can be considered to be a point magnetic induction detector.

(ii) The antenna array 1 separates the determination of the X and Y components. For each set of dipoles 2 (X and Y) the signal is insensitive to sensing coil position along the longitudinal axis of each set.

(iii) The width of each coil (dipole is sufficiently small) that the field produced by each antenna can, to a good approximation be considered as the derivative with respect to wire location of the field due to a long single wire.

Even with these simplifications there is no exact analytic method for the determination of X,Y,Z coordinates of a sensing coil. Rather approximate iterative schemes have to be employed. Applicants method has two steps:

(a) The first step makes use of the spatial properties of the functions described below in order to get a first estimate of the X,Y,Z coordinates from the mutual inductance measurements associated with respectively the X and Y dipole sets. This very much reduces the range over which the second stage has to search in order to fit the model equations to the data.

(b) In the second step, an iterative algorithm searches the reduced region of the X,Y axes checking at each stage that the revised estimates provide a better fit to the data.

In this scheme two independent estimates of Z are obtained and these can be used as a check on the accuracy of the final estimates.

WO 92/03090

PCT/GB91/01431

-11-

The following is a more detailed description of steps (a) and (b).

Hence, the equations to be solved are:

The equation for the mutual inductance between an infinitely long straight wire, parallel to the Y axis at coordinate  $x_i$ , and a coil 7 at coordinate  $x, y, z$  is:

$$M_i = (n_x z + n_z (x_i - x)) / ((x_i - x)^2 + z^2) \quad (1)$$

where  $[n_x, n_y, n_z]$  is a vector in the axial direction of the coil whose magnitude is dependent on the current in the wire, and the size and number of turns of the coil. A similar equation relates mutual inductance to position for wires parallel to the X-axis.

For the case of a dipole 2 replacing the infinite wire, we make the approximation that the mutual inductance is the differential of the equation for magnetic flux induced in coil B when a current  $i$  flows in a coil A (that is  $\phi_A = M_{AB} i_B$ ) with respect to  $x$ , which yields

$$M_i' = (2n_x z (x_i - x) + n_z ((x_i - x)^2 - z^2)) / ((x_i - x)^2 + z^2)^2 \quad (2)$$

It is also convenient to consider the second differential of  $M_i$ , since the stationary points of the dipole equation are of interest. It is:

$$M_i'' = (2n_x z (3(x_i - x)^2 - z^2) + 2n_z (x_i - x) ((x_i - x)^2 - 3z^2)) / ((x_i - x)^2 + z^2)^3 \quad (3)$$

The above equations assume that the wire length is infinite. However, in any practical application finite wires are used. A correction can be made to account for the fact that the induced voltage is less. Hence, referring to Figure 3, if  $\alpha_1$  and  $\alpha_2$  are the angles between lines joining a coil 7 to the ends of the transmitting wire and the perpendicular from the coil to the wire, then the

WO 92/03090

PCT/GB91/01431

-12-

induced voltage is reduced by:

$$2/(\sin(\alpha_1) + \sin(\alpha_2)) \quad (4)$$

A direct solution to the single wire equation is available. It is found by multiplying out equation (1) to give:

$$2M_1x_1x - M_1(z^2 + x^2) + x_1n_z + n_xz - n_zx - M_1x_1^2 = 0 \quad (5)$$

if we make the substitutions:

$$s_1 = (z^2 + x^2) \quad (6)$$

$$s_2 = (n_xz - n_zx) \quad (7)$$

we obtain a linear equation in four variables,  $x, nx, s_1$  and  $s_2$ , which can be solved with four readings ( $i=0,1,2,3$ ) from four wires. The values of  $z$  and  $n_z$  can be obtained from the simple quadratic equations (6) and (7) after solution of the four linear equations.

An experimental system has been devised to try this solution method, using an area of 100 sq. cm., and it was found to work well for values of  $z$  greater than 5cm. It is believed that with further attention to the computation a stable solution could be obtained by this method over the required operating range.

Since this method depends critically on the relative magnitudes of the readings taken from the individual wires, the finite length  $\alpha$  correction factors must be applied. Addition of these correction factors raises the order of this solution such that it becomes incomputable directly. However, an iterative scheme can be applied simply, as follows:

(i) Compute an estimate of the position of a sensing coil 7 using the direct linear solution.

WO 92/03090

PCT/GB91/01431

-13-

(ii) For each measurement, compute the  $\alpha$  correction based on the coil's estimated position. Correct the measured value by the inverse of this factor.

(iii) Recompute the estimate of the sensing coil position.

(iv) If the new estimate is sufficiently close to the old estimate then terminate, otherwise go to step (ii).

This algorithm has been found to work satisfactorily with simulated data. However, further investigation has been suspended in view of the better results obtained using dipole antennas 2 rather than single wires.

Although there are only four unknowns in the dipole equation (2), the fourth order terms means that a direct solution is not available from four sets of readings.

The fourth order terms in the dipole equation means that, despite the fact that there are only four unknowns, a solution cannot be obtained directly from four measurements. Either an iterative solution must be used, or an over specified system of equations is required. The latter may be done by the same method outlined above. Multiplying out the dipole equation, and grouping the terms with common coefficients, we obtain:

$$M_i x_i - 4M_i x_i^2 (3x^2 + z^2) - 4M_i x_i (x^3 + xz) + M_i (x^4 + z^4 + 2x^2 z^2) - x_i^2 n_z + 2x_i (n_z x - n_x z) + (2n_x z x + n_z x^2) = 0 \quad (8)$$

as before we can linearise equation (3) by substituting:

$$s_1 = (3x^2 + z^2) \quad (9)$$

$$s_2 = (x^3 + xz) \quad (10)$$

$$s_3 = (x^4 + z^4 + 2x^2 z^2) \quad (11)$$

$$s_4 = (n_z x - n_x z) \quad (12)$$

$$s_5 = (2n_x z x + n_z x^2) \quad (13)$$

WO 92/03090

PCT/GB91/01431

-14-

to obtain a system of equation in seven variables ( $x, nz, s1, s2, s3, s4, s5$ ). After solution values for  $z$  and  $nx$  may be obtained from further solution of equations (9-13). This solution has not been tested for the following reasons. Firstly, since it depends on the magnitudes of the seven measured points, it is necessary to correct for the finite lengths of the dipoles. This requires an iterative process which includes a gaussian elimination on a seven by seven matrix and, consequently, is computationally very slow. Secondly, the presence of fourth order terms makes the method less robust against error.

Accordingly, a fast iterative algorithm has been developed for solution of the field equations. It can be formulated for both single wires or dipoles. By way of example, the latter form is presented below.

The algorithm is based on the fact that the equation is a linear combination of two components:

$$z z(x_i - x) / ((x_i - x)^2 + z^2)^2 \quad (14)$$

and

$$(x_i - x)^2 - z^2) / ((x_i - x)^2 + z^2)^2 \quad (15)$$

These are shown in Figure 4. The  $nz$  component has a peak at the position of the coil and zeros at a distance of  $z$  from the peak, and the  $nx$  component has a zero at the same place, and two peaks at a distance  $z\sqrt{3}$  from the position of the coil. In Figure 4, the curves are drawn assuming positive  $nx$  and  $nz$ . Summing these two curves, the resulting graph must have a zero to the right of the peak, at the point where the positive ( $nx$ ) component equals the negative ( $nz$ ) component. This zero must occur at a distance of less than  $z$  from the position of the coil. The summed graph must also have a peak to the left of the coil



WO 92/03090

PCT/GB91/01431

-15-

position. It will occur when the negative slope of the  $n_z$ -component is equal to the positive slope of the  $n_x$ -component. This will be somewhere between the coil position, where the slope of the  $n_z$  component is zero, and the negative peak of the  $n_x$  trace, where its slope falls to zero. Hence, the peak is at most  $z/\sqrt{3}$  from the coil position. The summed curve will also have a smaller peak at a distance of greater than  $z$  to the right of the coil, and possibly another peak and zero to the left of the coil. It is clear to see that (for  $n_z > 0$ ) these peaks must be smaller in magnitude than the one close to the root close peak, since the amplitude of both traces fall off sharply with distance from the coil position. Similarly, it is clear to see that the other zero, if present, is further from the main peak. Hence, for a give set of measurements, it is known that the coil is located between the largest peak and its closest zero, which are closer together than  $z(1+1/\sqrt{3})$ . Similar arguments apply to the cases where  $n_x$  and  $n_z$  are both negative, or of different signs.

The algorithm is a binary search of the space between the largest peak and its closest zero. If an estimate is made of the coil position, say  $x_c$ , and we write:

$$uz = x_c - x_z \quad (16)$$

$$up = x_c - x_p \quad (17)$$

where  $x_z$  and  $x_p$  are the positions of the peak and the zero, then the following equations result:

$$Mg = n_z / z^2 \quad (18)$$

$$Mp = (2n_x z up + n_z (up^2 - z^2)) / (up^2 + z^2) \quad (19)$$

$$2n_x z uz = -n_z (uz^2 - z^2) \quad (20)$$

$$2n_x z (3up^2 - z^3) = -2n_z up (up^2 - 3z^2) \quad (21)$$

WO 92/03090

PCT/GB91/01431

-16-

For the most accurate estimate, equations (18), (20) and (21) can be solved to provide an estimate for  $n_x, n_z$  and  $z$ . The resulting graph is then compared with the real data. For points outside the peak to nearest zero span, an estimate too close to the zero results in the estimated magnitudes being too high, and vice versa, which gives a simple criterion for choosing how to improve the estimate  $x_c$ , by binary search. Equation (19) was used as an alternative to equation (21) in the current study. It has the advantage that the position of the peak need not be known, any magnitude will suffice. However, it produces a less accurate solution, since it depends on a measured magnitude, at or near to the peak, and hence requires compensation for the finite dipole lengths. Note that the positions of the peaks and zeros are not altered by the dipole lengths.

Two problems have been found with the method described above. Firstly, in some cases it is possible that the closest zero is not within the measured range. This can be partly solved by extrapolation of the measured data, but this technique is error prone, and therefore undesirable. If the measured range is extended by the maximum operating height beyond the position range in which the coil is to be located, then this problem will never arise. This is possible for the endoscope application in one dimension. Having solved for that direction, use can be made of the known value of  $z$  to provide a more accurate extrapolation in the other direction.

The second problem is caused when the values of  $n_x$  and  $n_z$  are both close to zero. In this case very low measurements are obtained. This condition can be identified, since in the orthogonal direction the trace has a clearly defined zero with symmetrical peaks. One possible solution in this case is to use an alternate set of coils, configured to provide the localisation for this special

WO 92/03090

PCT/GB91/01431

-17-

case. Since everything about the coil, except its x (or y) coordinate is known, this arrangement can be kept very simple.

Whilst a particular embodiment has been described, it will be understood that modifications can be made without departing from the scope of the invention, as defined by the appended claims. For example, whilst a seven by seven antenna array 1 is shown and described, larger planar grid arrays are possible. Moreover, instead of mounting the sensing coils 7 at fixed positions about the endoscopic probe, one or more coils with connecting leads for coupling to associated preamplifiers may be disposed at intervals inside a protective plastics sheath capable of being inserted and moved longitudinally of the probe along the biopsy channel of the endoscope. Instead of providing each sensing coil 7 with its own individual chain of circuits 9, 10 and 11, a multiplexing system may be used sequentially to connect the sensing coils to a single such chain. The microprocessor 12 may control switching of the relay box 4 to produce energisation of the dipole antennas 2 of the array 1 in a predetermined sequence.

WO 92/03090

PCT/GB91/01431

-18-

CLAIMS

1. A probe system for use in an enclosed, non-conducting environment and including a probe (6), characterised by at least one sensing coil (7) movable with the probe, an array (1) of antennas (2), an electrical source (4,5) for supplying each antenna, either simultaneously or sequentially, with an AC electrical signal for inducing a corresponding electrical signal in the or each sensing coil, and electronic processing means (12) connected to the sensing coil(s) for processing the induced signals and producing an indication of the three dimensional location of the probe (6) with respect to the antenna array (1).
2. A probe system according to claim 1, characterised in that the electrical source (4,5) is adapted to supply the antennas (2) with audio frequency AC electrical signals.
3. A probe system according to claim 1 or 2, characterised in that the antenna array (1) comprises two sets of antennas (2) arranged in a substantially mutually orthogonal array and respectively defining X and Y axes.
4. A probe system according to claim 1, 2 or 3, characterised in that the antenna array (1) is a substantially planar array.
5. A probe system according to any preceding claim, characterised in that at least some of the antennas (2) are dipole antennas.
6. A probe system according to claim 5, characterised in that each dipole antenna (2) comprises an elongated coil with opposite ends (3) configured to produce a net dipole at right angles to the longitudinal axis of the antenna.
7. A probe system according to any preceding claim, characterised in that the probe (6) comprises an elongated element and in that a plurality of sensing coils (7) are disposed at spaced positions along the length of the probe.

WO 92/03090

PCT/GB91/01431

-19-

8. A probe system according to any preceding claim, characterised in that the probe (6) is an endoscope and the sensing coil or coils (7) are disposed in the biopsy channel of the endoscope.

9. A probe system according to any preceding claim 1 to 8, characterised in that the or each sensing coil (7) is mounted on the probe (6) substantially coaxially therewith.

10. A probe system according to any preceding claim, characterised in that the or each sensing coil (7) is connectable to the processing means (12) via a phase sensitive detector (10) which produces a demodulated DC analogue voltage proportional to the AC voltage signal induced in the associated sensing coil.

11. A probe system according to claim 10, characterised in the sensing coil (7) is connected to the phase sensitive detector (10) via preamplifying means (9) and the phase sensitive detector is connected to the processing means (12) via an A/D converting means (11) which converts the DC signal produced by the detector (10) into a digital signal for processing by the processing means (12).

12. A probe system according to any preceding claim, characterised in that the electrical source (4,5) is adapted simultaneously to supply each antenna (2) of the antenna array (1) with an AC electrical signal of distinct frequency.

13. A method of locating a probe (6) within the body of a human or animal subject, characterised by the steps of inserting the probe into the body of the subject, said probe having at least one sensing coil (7) movable therewith, disposing an array (1) of antennas (2) adjacent the subject, energising each of the antennas (2), either simultaneously or sequentially, with an AC electrical signal, detecting the resulting signal induced in the or each sensing coil (7), and processing the detected signal(s) to

WO 92/03090

PCT/GB91/01431

-20-

produce an indication of the three dimensional location of the probe with respect to the antenna array.

14. A method according to claim 13, characterised by the step of detecting the signal induced in one or more reference coils disposed externally of the body of the subject, thereby to establish the location of the body of the subject with respect to the antenna array (1).

WO 92/03090

PCT/GB91/01431

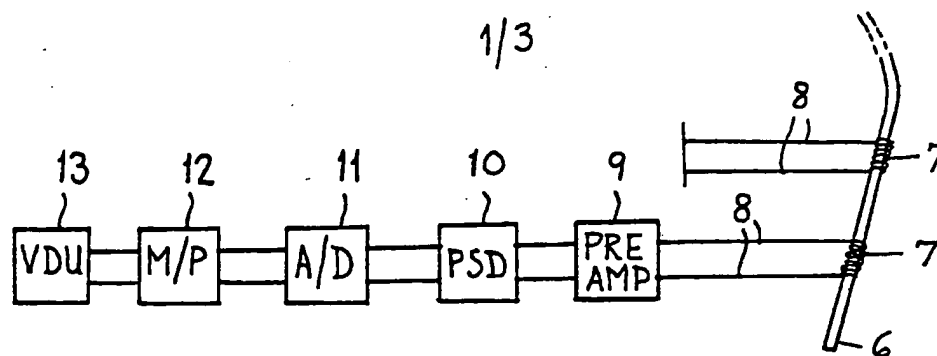
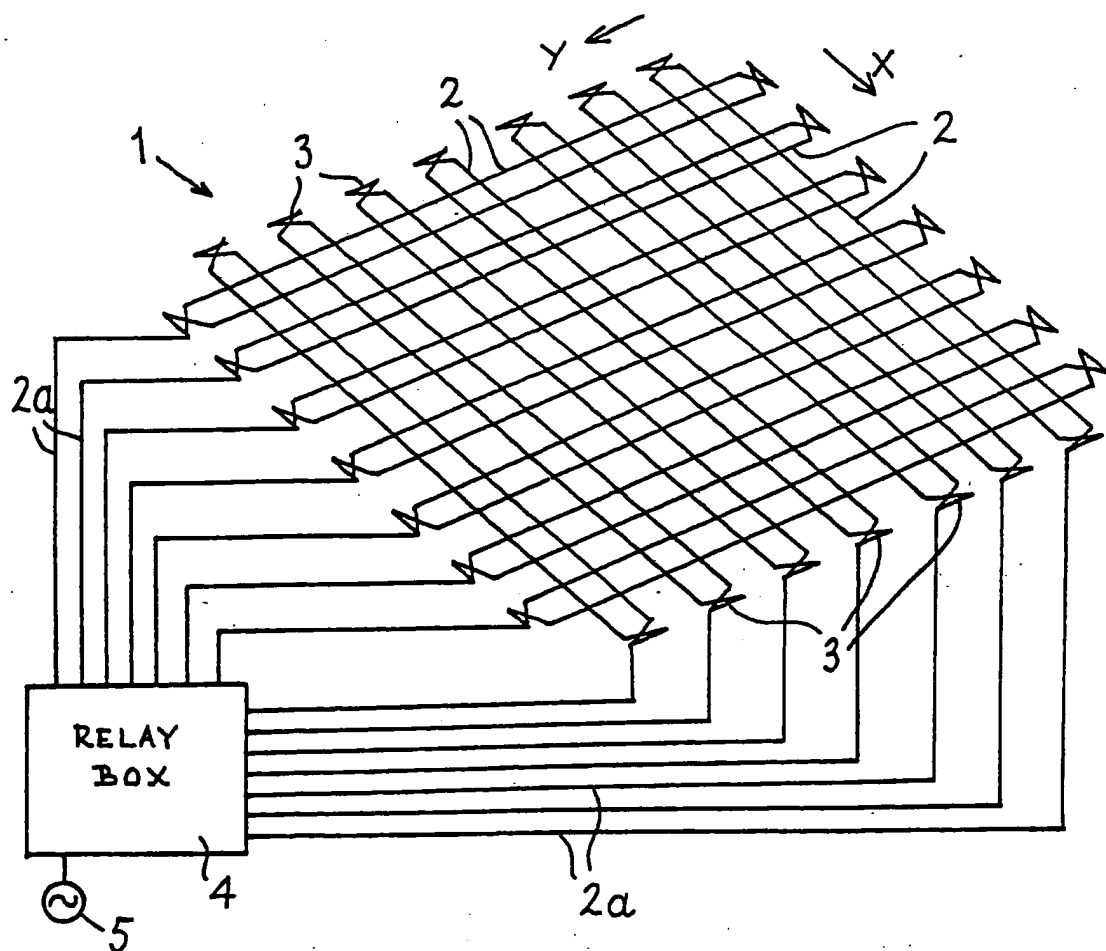


Fig.1



SUBSTITUTE SHEET

WO 92/03090

PCT/GB91/01431

2/3

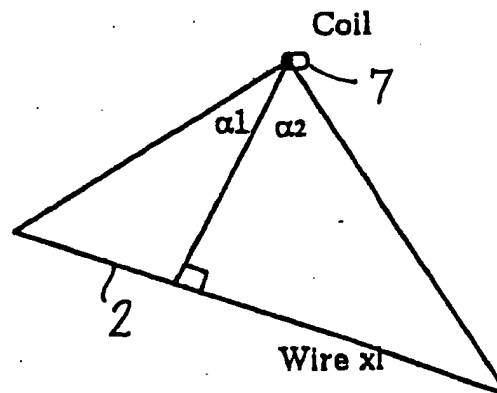
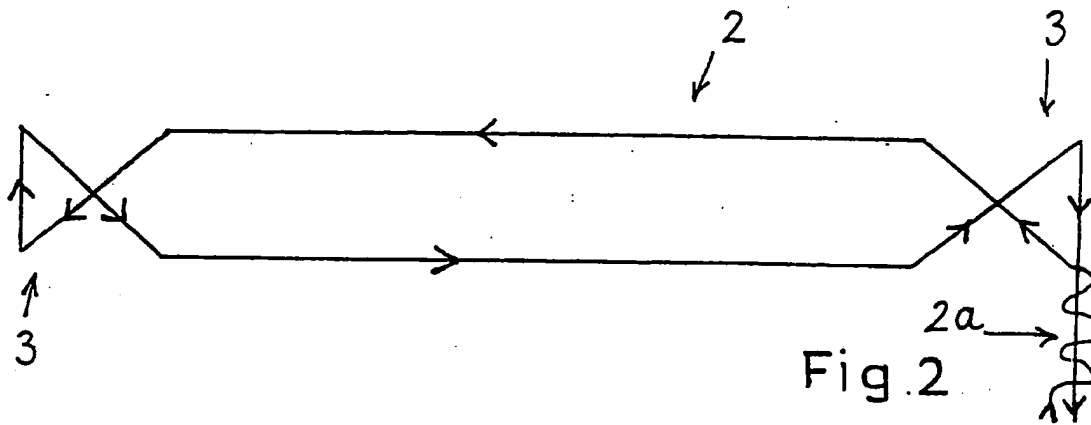


Fig. 3

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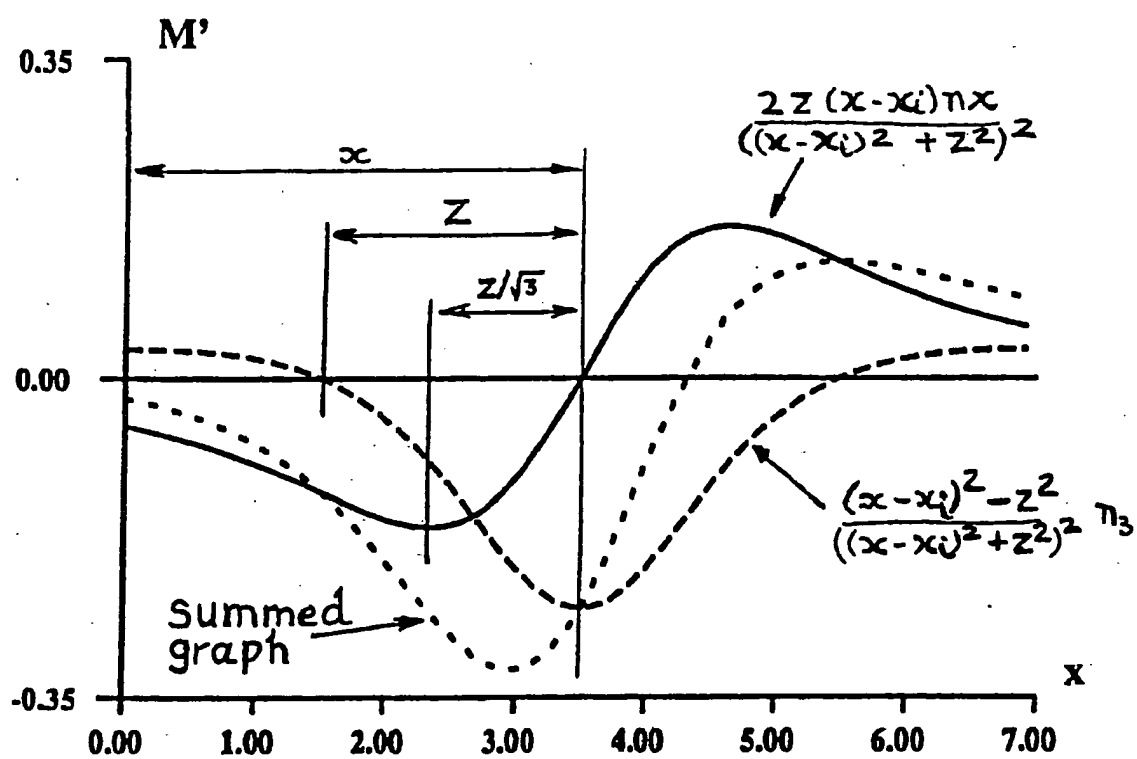


WO 92/03090

PCT/GB91/01431

3/3

FIG. 4




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## INTERNATIONAL SEARCH REPORT

PCT/GB 91/01431

International Application No

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (If several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int.Cl. 5 A61B5/06; G01V3/10		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl. 5	A61B ; G01V	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	US,A,4 317 078 (H.R. WEED ET AL.) 23 February 1982	1-4,8,9
X	see column 4, line 46 - column 5, line 11 see column 11, line 4 - column 12, line 16 see figures 17,18	13,14
A	US,A,4 114 601 (M.A. ABELS) 19 September 1978	1,3-6
A	see column 2, line 58 - column 4, line 41 see figures 1,2	12-14
A,P	EP,A,0 399 536 (MICRONICS PTY LTD.) 28 November 1990	1,3,9-11
A,P	see page 3, line 19 - page 5, line 25 see figures 1-8	13,14
A	EP,A,0 359 697 (PHARMACIA DELTEC, INC.) 21 March 1990	1,8-10
A	see column 3, line 15 - column 5, line 26 see column 9, line 12 - line 62; figure 1	13
	--- -/-	
<p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
22 NOVEMBER 1991	- 2. 01. 92	
International Searching Authority	Signature of Authorized Officer	
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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A A	GB,A,891 754 (TELEFUNKEN G.M.B.H.) 21 March 1962 see page 2, line 2 - line 30; figure 1  ---	1,3,9,10 13,14

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. GB 9101431  
SA 50874**

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on  
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4317078	23-02-82	None	
US-A-4114601	19-09-78	US-A- 4193405	18-03-80
EP-A-0399536	28-11-90	None	
EP-A-0359697	21-03-90	US-A- 4905698	06-03-90
		AU-A- 4227589	02-04-90
		EP-A- 0434745	03-07-91
		WO-A- 9002514	22-03-90
GB-A-891754		None	

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